Physiological Assessments of Permeable NBC Protection Clothing for Hot Climate Conditions

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1 Introduction

Against the background of the increasingly less clearly calculable and thus still present NBC threat, NBC protection is of highest priority in all modern armies today. Therefore, individual NBC protection, including the ability to carry out actions under NBC conditions, is very important. Especially, the direct protection of the soldier against the effects of applied NBC and incendiary weapons on his sensitive organism calls for the consequent consideration of these aspects even under the mission conditions to be expected in the future.

As individual NBC protection does not only represent the sum of the parts of the personal NBC protection equipment of the soldier individual NBC protection must be regarded as a whole taking the present and future requirements into consideration, and must correspond to the potential danger.

As the NBC protection function can not be fulfilled by any other kind of soldier's equipment the clothing physiology of the personal NBC protection equipment (including breathing and body protection) should be so that the wearer does not consider it to be a hindering „foreign body" that disturbs his actions.

Reliable breathing protection is absolutely necessary for the survival and function of the Soldier System as the incorporation of toxins via the respiratory tract is very dangerous for the human organism.

As chemical warfare agents can enter the human body not only via the respiratory tract but also via the skin the complete body must be protected against the influence of warfare agents. Therefore, it must be noted that the soldier can absorb a lethal dose of chemical warfare agents to be expected in a combat within only two minutes via the unprotected skin of the head and hands alone.

In addition to fulfilling the protection requirements, an important function of a permeable NBC protective suit is to regulate the heat and moisture exchange of the wearer with the environment so that it does not lead to overheating (hyperthermia) or undercooling (hypothermia). On principle, operating situations can always be problematic when a high energy consumption must be compensated for with intense heat production, for example when wearing NBC protective clothing in hot and moist (sub-tropical) climatic zone. In such cases there is the danger that the thermal balance (heat formation in organism = heat emission to the surroundings) will be interfered with and at times resulting in extreme over-heating (heat stress).

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The stress resulting from the environmental situation comes in addition to the stress stemming from the wearing of the personal NBC protective equipment (NBC protective clothing, NBC respirator with filter canister, NBC overboots and NBC protective gloves), the enormous physical strain of the mission and additionally the weight of the equipment that the soldier must carry.

The task of equipping NBC protective clothing with good clothing physiological wearer characteristics has only been inadequately carried out up to now. That this point just as important is as the actual protective characteristics of the clothing is demonstrated by the experiences and discoveries during the Gulf War. Additionally, the increase in the requirement of the UN and NATO peace missions and the formation of crisis reaction troops has led to a further development in NBC protective clothing.

NBC protective clothing, which is lightweight and keeps the physiological stress of the wearer to the minimum, is being increasingly required. To keep the stress which results from wearing NBC protective clothing to a minimum, NBC protective clothing must be optimally designed regarding the clothing physiological aspect.

2 Structure and Functional Mechanism of an NBC Protective Clothing System

An NBC protective clothing system mainly consists of a multi-layer textile air-permeable surface compound with a shell fabric and a filter laminate each of which has a special function *[Figure 1]*.

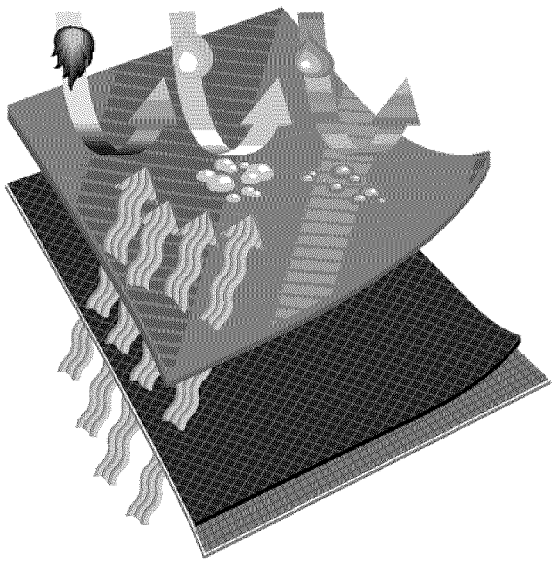

Figure 1: Structure of an air-permeable NBC protective clothing system

The strong barrier effect of the shell fabric (outer layer) prevents the penetration of radioactive particles or pathogenes passing through the textile surface compound. In addition, the oil and water repellent impregnation of the shell fabric prevents the absorption of liquid chemical warfare agents. The flame-retardant quality of the shell fabric as well as the thermal absorption capacity of the activated carbon, especially when being distributed homgeneously on the surface (this is e.g. very well developed in activated carbon fabric), provides protection against thermal effects. Specific requirements of missions at sea, e.g. resistance to water penetration, can be met by the integration of suitable permeable or semi-permeable membranes in the textile surface compound.

The filter laminate (inner layer with integrated activated carbon adsorber component) consists of a multi-layer compound structure in which an adsorber material (either activated carbon impregnated PU-foams, activated carbon spheres„ textile activated carbon adsorber, etc.) is embedded thus protecting the wearer of the suit against aerosol and gaseous chemical warfare agents by adsorption by the specific active surface.

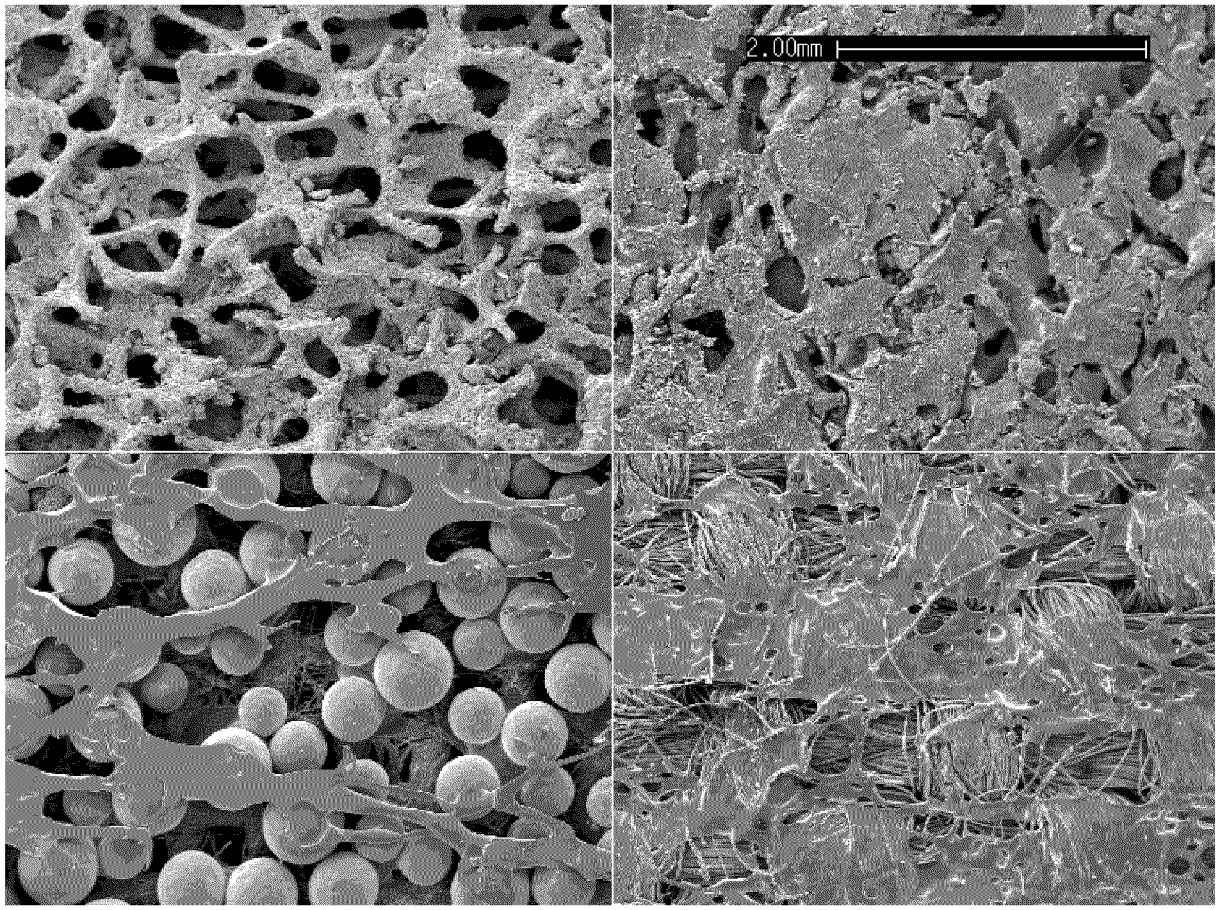

Figure 2: REM photographs of activated carbon adsorber materials:

Top left:	Activated carbon impregnated PU foam (open cell)
Top right:	Activated carbon impregnated PU foam (compressed)
Below left:	Activated carbon spheres (covered by PU net)
Below right:	Activated carbon fabric (covered by PU net)

The extremely high requirements of such an NBC protective clothing system are summarised in table 1.

Table 1: Requirements of an air-permeable NBC protective clothing system

- **Clothing physiological wearer comfort**
  - lightweight
  - optimal heat and moisture transport capability
  - controlled air-permeable textile layers
  - convenient design for good freedom of movement
  - no skin irritations
- **Protection against convective and/or radiation heat as well as direct influence of incendiary weapons (Napalm, etc.)**
  - flame-retardant properties
  - strong thermal absorption properties of the activated carbon component
- **Protection against mechanical influences**
  - high durability (tensile and tear resistance)
- **Resistance against POL's**
  - oil-repellent properties
- **Protection against specific chemical warfare agents**
  - multi-layer system structure with integrated activated carbon layer
- **Protection against contact with radioactive fallout or biological warfare agents**
  - multi-layer system structure and respective material thickness
- **Infrared reflectance**
  - IR remission of the shell fabric
- **Easy care**
  - washing at minimum 40 °C
  - dirt-repellent properties
- **Reuseability**
  - decontaminability
- **Compatibility**
  - with the other equipment components of the soldier
- **Easy and reliable handling**
  - also under stress

3 Clothing Physiological Wearer Comfort of NBC Protective Clothing

Situations in missions can always be problematic for the wearer of NBC protective clothing when his body is stressed and thus a high energy conversion (metabolic rate) has to be balanced by intensive heat production. This happens especially to wearers of NBC protective clothing in hot or muggy (sub-tropical) climatic zones. In these cases there is a danger of a disturbance of the thermophysiological balance (heat production in the organism = heat emission to the environment) and creation of a state of temporary extreme over-heating of the body (heat stress).

In addition to the stress resulting from the climatic conditions of the environment, there are other kinds of stress caused by the wearing of personal NBC protective equipment (NBC protective clothing, NBC protective mask with filter, NBC overboots and NBC protective gloves), the enormous physical stress arising from the action itself, and the weight of the other equipment the soldier has to carry. To keep the stress resulting from wearing the NBC protective clothing as low as possible the NBC protective clothing must ensure optimal clothing-physiological wearer comfort. For this reason, there is an increased demand for light NBC protective clothing systems which are less stressing with regard to clothing physiology.

In a critical evaluation, these principal requirements can not be fulfilled by an "NBC overgarment", i.e. an NBC protective clothing which is to be worn over the combat suit *[Figure 2 and 3]*.

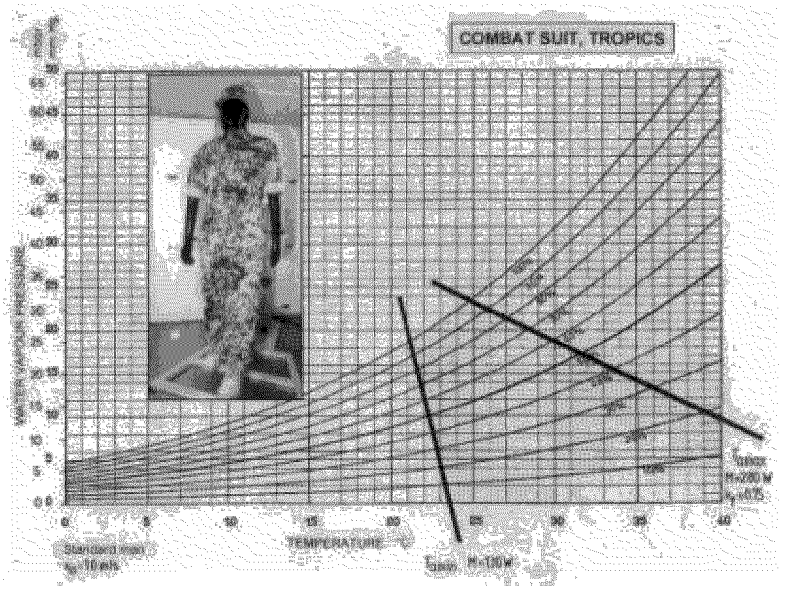

Figure 2: Wearer-physiological application area of a combat suit (yellow area)
(Source: Hohenstein Research Institute)

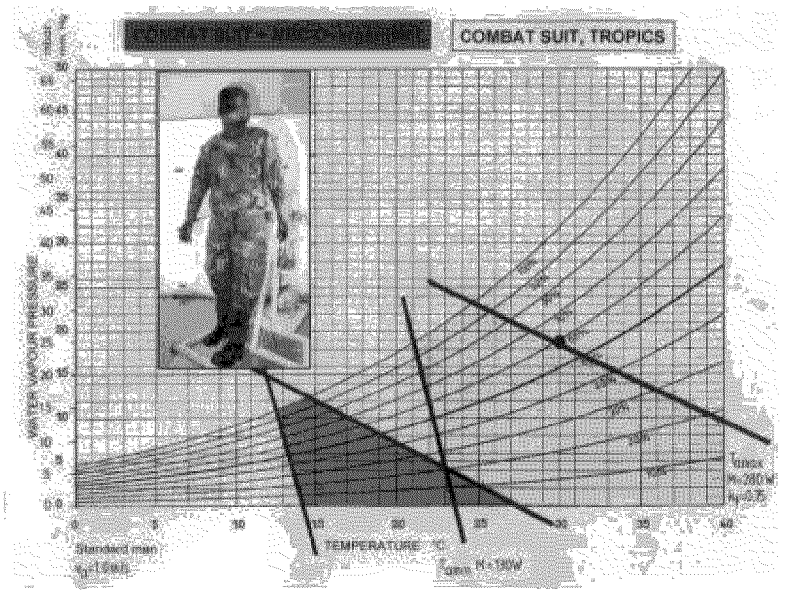

Figure 3: Wearer-physiological application area of an "NBC Overgarment" to be worn over a combat suit (blue area)
(Source: Hohenstein Research Institute)

3.1 Aspects, Components and Specific Parameters of the Wearer Comfort

The clothing-physiological wearer comfort mainly results from the following three factors:

- Thermophysiological wearer comfort
- Skin-sensoric wearer comfort
- Ergonomic wearer comfort

Clothing fulfills its wearing function and can be called "comfortable" *[Table 2]* if it has an optimal heat and moisture transport capability and a buffer effect, prevents unconvenient sensations when coming into contact with the skin, and does not hinder the freedom of movement of the wearer.

Table 2: Aspects, components and specific parameters of the wearer comfort

Aspect	**Components**	**Specific parameters**
Thermophysiological wearer comfort	Ensuring an even heat balance Avoiding the sensations "too hot" or "too cold"	Water-vapour resistance Heat insulation Moisture transfer index Air permeability Moisture compensation index Water-vapour absorption capacity Moisture compensation index Sweat transport Drying time Capillary transport
Skin-sensoric wearer comfort	Avoiding unconvenient sensations when coming into contact with the skin (no irritations such as scratching, itching, adhering to sweaty skin)	Adhesion index, surface index and moistening index Number of contact points between textile material and skin Stiffness
Ergonomic wearer comfort	Avoiding unconvenient heaviness and uncomfortableness Ensuring freedom of movement Optimal fit to the body Design	Fit Weight

4 Test Objectives

In the test carried out at Hohenstein Research Institute, two NBC protective clothing sets (Clothing system 1 and 2) *[Tables 3 and 4]* were tested for their usability in hot climatic zones with regard to clothing physiology *[9]*. The test objectives were:

- Measuring the thermal and water-vapour resistance of the individual textile layers of the clothing systems using the thermoregulatory model of the human skin (skin model)
- Measuring the thermal resistance (heat insulation) and determination of the water-vapour resistance of the complete clothing systems using the thermoregulatory model of the human being (thermal manikin "Charlie")
- Determination of the application area of the clothing systems under defined climatic conditions with the help of clothing-physiological predictive calculations

Table 3: Test samples

Description	Clothing system 1	Clothing system 2
Material structure:	Two-layer material structure (shell fabric + filter laminate containing activated carbon)	Two-layer material structure (shell fabric + filter laminate containing activated carbon)
Activated carbon component:	Activated carbon fabric	Activated carbon spheres
Tailoring:	Two-piece (jacket with integrated hood and trousers)	Two-piece (jacket with integrated hood and trousers)
DB3 method and vapour test acc. to TK-BA 34-8415-048	>6 hours	>6 hours

Table 4: Mechanical-technological parameters of the test samples*

Parameter	Clothing system 1	Clothing system 2	Test according to
Surface weight (g/m²)	467	558	DIN EN 12 127
Air permeability (mm/s)	127	63.2	DIN EN ISO 9237

** Tested on the shell fabric in combination with the filter laminate*

4.1 Quantitative Measurement of the Wearer Comfort

The measuring methods described in detail hereafter *[Table 5]* were applied for the quantitative determination of the biophysiological parameters of the clothing systems.

Table 5: Applied measuring methods

Measuring method	Description	Measuring equipment
Stationary measuring method	Thermoregulatory model of the human skin	Skin model
Dynamic measuring method	Thermoregulatory model of man	Thermal manikin "Charlie" of Hohenstein Research Institute

4.1.1 Thermoregulatory Model of the Human Skin (Skin Model)

The biophysical parameters, i.e. thermal resistance (R_{ct}) and water-vapour resistance (R_{et}) of the individual textile layers of the clothing systems *[Table 6]* and underwear *[Table 7]* were determined quantitatively using the thermoregulatory model of the human skin.

The skin model consists of a plate which is heated to the temperature of the human skin. The plate is supplied with water which can evaporate through a large number of pores like the human skin. The skin model is placed in a climate box which can be adjusted to different environmental conditions (such as temperature, humidity and wind speed). This measuring method is established in national and international standards *[6]*.

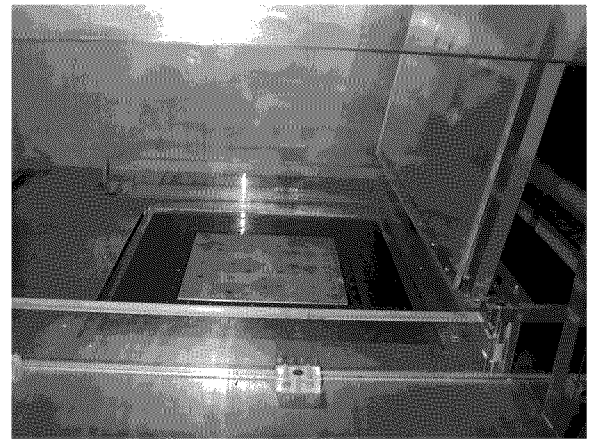

Figure 4: Skin Model, Inside View

Table 6: Biophysical parameters of the test samples

Parameter	Measuring unit	Clothing system 1	Clothing system 2
Water-vapour resistance (R_{et})	m^2Pa/W	6.21	10.53
Thermal resistance (R_{et}) x 10^{-3}	m^2K/W	13.1	23.2

Table 7: Biophysical parameters of the underwear

Parameter	Measuring unit	Pants (short)	T-shirt (short sleeve)
Water-vapour resistance (R_{et})	m^2Pa/W	3.35	3.78
Thermal resistance (R_{et}) x 10^{-3}	m^2K/W	13.0	13.3

4.1.2 Thermoregulatory Model of Man (Thermal Manikin "Charlie")

A whole-body thermo-dummy was used to evaluate the total effect of the clothing systems including the interaction between underwear *[Table 6]* and outerwear under conditions which are as close to reality as possible *[Table 7]*.

The life-size manikin "Charlie" (Hohenstein Research Institute) has a human shape and is a size 50 (medium size), it has mechanically movable arms and legs, and represents a thermoregulatory model of man. It can be provided with the body and skin temperature of man by electrical heating lines in the inside of the manikin's body. In addition, the quantity of heat leaving the body of the manikin and passing through the clothing can be adjusted. This makes it possible to quantitatively determine the heat insulating effect of the clothing systems possible in a certain environmental climate. This climate is adjusted in the climate box in which the manikin is placed.

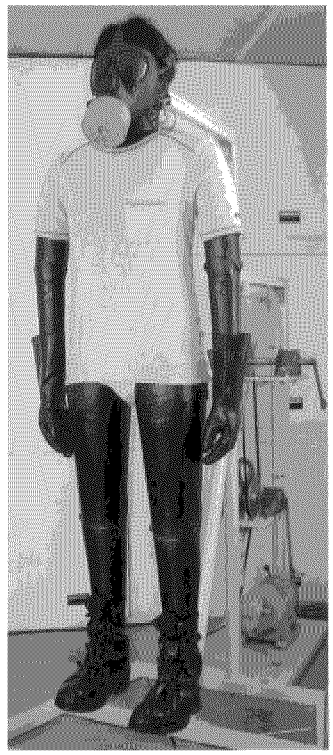

Figure 5:
Thermal manikin "Charlie" wearing underwear

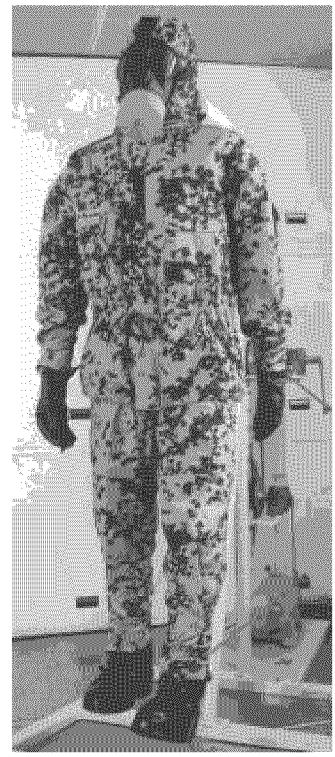

Figure 6:
Thermal manikin "Charlie" wearing clothing system 1

Figure 7:
Thermal manikin "Charlie" wearing clothing system *2*

The following combinations (underwear, protective equipment components) of the clothing systems 1 and 2 were tested on thermal manikin "Charlie" *[Figure 5]*:

Underwear:	Pants (short), made of 100 % CO
	T-shirt (short sleeve), made of 100 % CO
NBC protective equipment:	NBC protective mask with NBC filter
	Cotton under-gloves
	Impermeable NBC protective gloves
	Socks made of 80 % CO/ 20 % PA
	Field boots
	Impermeable NBC overboots

Table 8: Chosen climate conditions

Parameter	**Value**
Temperature:	+40 °C
Humidity:	30 % r. h.
Wind speed:	1 m/s

A metabolic rate of **M = 280 W** was chosen for the tests. This is equal to a typical average activity while wearing NBC protective equipment.

4.2 Results

Together with the Skin Model test *[Table 6 and 7]* and predictive calculations, the wearer-physiological application area and the time-pattern of rectale temperatur of the clothing systems 1 and 2 at defined climatic conditions *[Table 8]* and work intensities (M = 280 W), was determined.

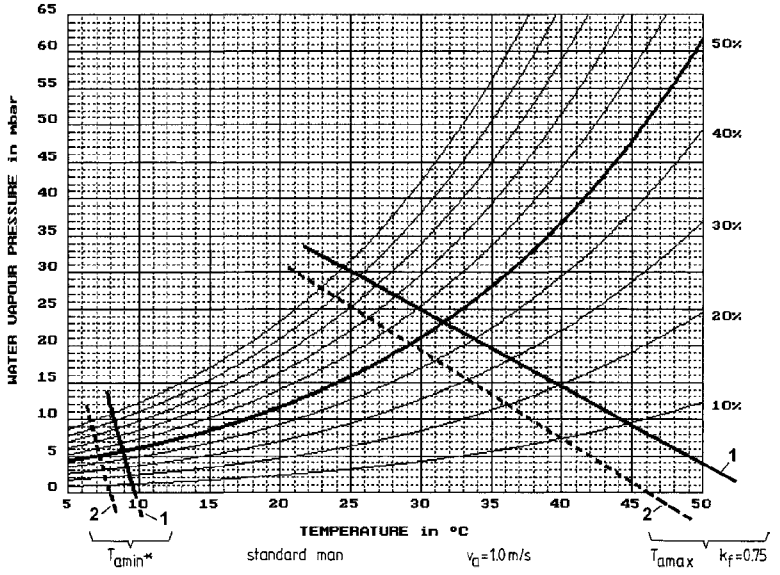

Figure 8: Wearer-physiological application area
———— Clothing system 1
---------- Clothing system 2

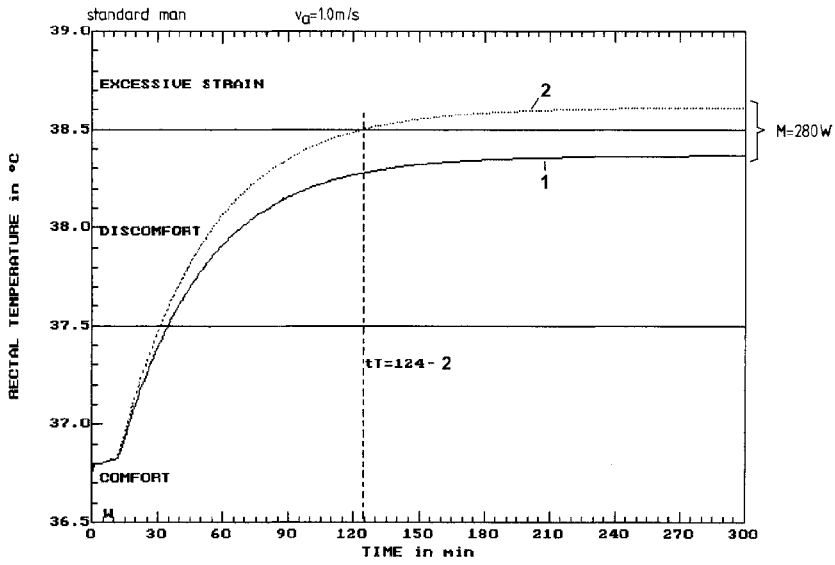

Figure 9: Time-pattern of rectale temperature
———— Clothing system 1
---------- Clothing system 2

5. Discussion

Whereas both of the tested NBC protective suits are able to protect against specific chemical warfare agents for at least 6 hours they are considerably different with regard to clothing physiology. Under the chosen climatic conditions of +40 °C and 30 % r. h. and taking an activity level, i.e. a metabolic rate of M = 280 W into account, it is only possible to carry out missions under full NBC protection for almost 2 hours (124 minutes) wearing clothing system 2 until the physiological performance limit is reached and the wearer is endangered by collapse. *Only clothing system 1 can be worn in missions of more than 6 hours without putting a critical physiological burden on its wearer.*

The tests prove that it is important for the intended application purpose that

- the textile layers of the NBC protective clothing (shell fabric in combination with the filter laminate) have thermal and water-vapour resistance which are as low as possible

- the textile layers of the NBC protective clothing (shell fabric in combination with the filter laminate) have a high air permeability as much as possible.

Due to the tightly closed openings of the clothing, there is practically no ventilation inside an NBC protective clothing, i.e. there is no air exchange between the mirco-climate inside the suit and the environment outside via the openings of the clothing. Respective tests *[5]* have shown that the thermal resistance is reduced by up to 38 % due to a certain "blow-through effect". This is physiologically favourable in hot climates. However, effective air-permeable NBC protective clothing must always ensure an optimal ratio between the "blow-through effect" and the necessary protection performance against CWA, especially in vapour form. Therefore, this optimal solution can only be achieved by the integration of a homogenous adsorber material depending on the function of the total system and its individual components.

Especially in hot cimate zones, the comfort of the wearer can be considerably reduced while his body core temperature and pulse frequency are considerably increased. As an NBC overgarment is usually worn over the combat suit during a mission, the combination of clothing generated can be compared to a winter uniform with regard to clothing physiology, and does not at all meet the mission requirements of tropical regions. Tests carried out in hot climate zones show that wearing such combinations of clothing leads to heat stress within the shortest time so that the personnel is no longer able to fulfill their military missions. Even relatively short actions under full NBC protection can not be carried out.

The high requirements of reliable NBC body protection can only be realised by a new quality of combat clothing which must optimally combine the advantages of a combat suit with those of NBC protective clothing. The Safeguard™ 3002-A1 individual NBCF protection concept meets these technological requirements.

The combat suit with integrated NBC and F protection is worn directly over the underwear in place of the normal combat suit and at the same time replaces the personal NBC protective clothing (when worn together with the NBC protective mask, protective gloves and overboots). It prevents the wearer from direct skin contact with radioactive fallout, and biological and chemical warfare agents. Furthermore, it protects the wearer against thermal effects in the case of nuclear weapon detonations, incendiary weapons or fire (F protection).

Especially the experiences gained in recent missions of crisis reaction forces and the UN troops prove that surprise attacks such as hostile ambushes without prior warning e.g. with Napalm or self-made incendiary weapons such as "Molotov coktails" make immediate protection against thermal effects absolutely necessary.

Summary

Individual NBC protection can only be accomplished completely and effectively if all influencing parameters are considered separately and in the necessary extent from the beginning. Uncritical treatment of individual aspects and correlations as well as inadmissible simplifications will have fatal consequences.

The duration of actions under full NBC protection depends on the structure of the NBC protective clothing to a large extent. However, it will definitely be limited by the actual environmental influences. In the end, the soldier himself, his actions and decisions are the key to success even when being optimally provided with personal equipment, well trained and able to bear physical and psychological stress.

Together with an NBC protective mask, protective gloves and overboots, a combat suit with integrated NBC protection represents a complete set of NBC protection equipment which can be worn for quite a long period of time without considerable physical stress even under NBC conditions due to its air and water-vapour permeability. Due to its immediate availability it provides the soldier with permanent individual body protection so that the duration of actions under full NBC protection is no longer limited by the protection equipment itself and its negative effect on the fitness of the personnel for combat is considerably reduced.

References

[1] Umbach, K. H.,
Meßmethoden zur Prüfung physiologischer Anforderungsprofile an Zivil-, Arbeits- und Schutzbekleidung sowie Uniformen,
26. Internationale Chemiefasertagung, Dornbirn 20. – 22.05.1987

[2] Umbach, K. H.,
Tragekomfort von Kleidungskombinationen,
30. Internationale Chemiefasertagung, Dornbirn 12. – 14.06.1991

[3] Meechels, J.,
Körper-Klima-Kleidung, Grundzüge der Bekleidungsphysiologie,
Schiele & Schön, Berlin

[4] Umbach, K. H.,
Bekleidungsphysiologische Aspekte zur Entwicklung von Funktionstextilien,
Schulungsunterlagen, Technische Akademie Hohenstein e.V., 2000

[5] Umbach, K. H.,
Einfluss der äußeren Luftbewegung auf den Verwendungsbereich von Kleidung,
Hohensteiner Forschungsbericht, März 1982

[6] DIN EN 31 092, Messung des Wärme- und Wasserdampfdurchgangswiderstandes unter stationären Bedingungen

[7] Stoll, P. T.,
Clothing physiological aspects for the optimisation of permeable NBC protective clothing for operation in hot climates; Seventh International Symposium on Protection against CB Warfare, Stockhom, 2001

[8] Töpfer, H.-J.,
Individueller ABC-Schutz als integrierter Bestandteil des Systems Soldat,
Wehrtechnischer Report System Soldat, Bonn und Frankfurt a. M., Juni 1997

[9] Test Report No. Z0.4.3910/1, Hohenstein Institute for Clothing Physiology, 25th July 2001